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Dunne

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(54) **SELF-CALIBRATING PRECISION TIMING CIRCUIT AND METHOD FOR A LASER RANGE FINDER**

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This patent is subject to a terminal disclaimer.

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Related U.S. Application Data

(63) Continuation of application No. 09/234,724, filed on Jan. 21, 1999, now Pat. No. 6,057,910, and a continuation of application No. 08/918,396, filed on Aug. 26, 1997, now Pat. No. 5,880,821, and a continuation of application No. 08/717,635, filed on Sep. 23, 1996, now Pat. No. 5,703,678, and a continuation of application No. 08/375,941, filed on Jan. 19, 1995, now Pat. No. 5,574,552.

(51) **Int. Cl.**[7] **G01C 3/08**; G01P 3/36; G01S 13/00

(52) **U.S. Cl.** **356/5.1**; 342/203; 356/5.01; 356/5.05; 356/28

(58) **Field of Search** 356/5.05, 5.01, 356/28; 342/203

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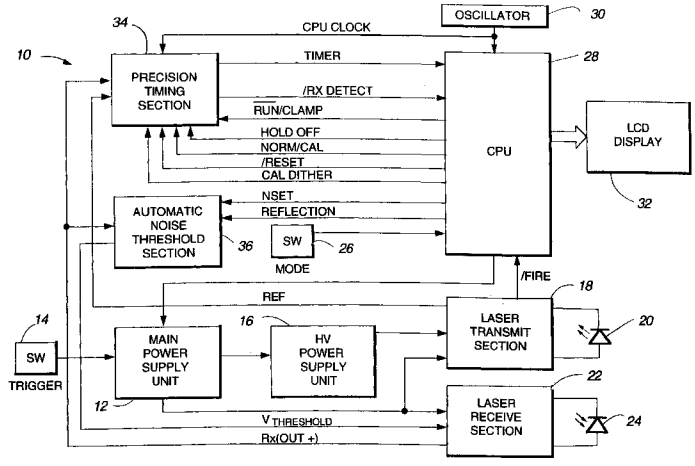
(57) **ABSTRACT**

A highly precise range measurement instrument is made possible through the use of a novel and efficient precision timing circuit which makes use of the instrument's internal central processing unit crystal oscillator. A multi-point calibration function includes the determination of a "zero" value and a "cal" value through the addition of a known calibrated pulse width thereby providing the origin and scale for determining distance with the constant linear discharge of capacitor.

13 Claims, 8 Drawing Sheets



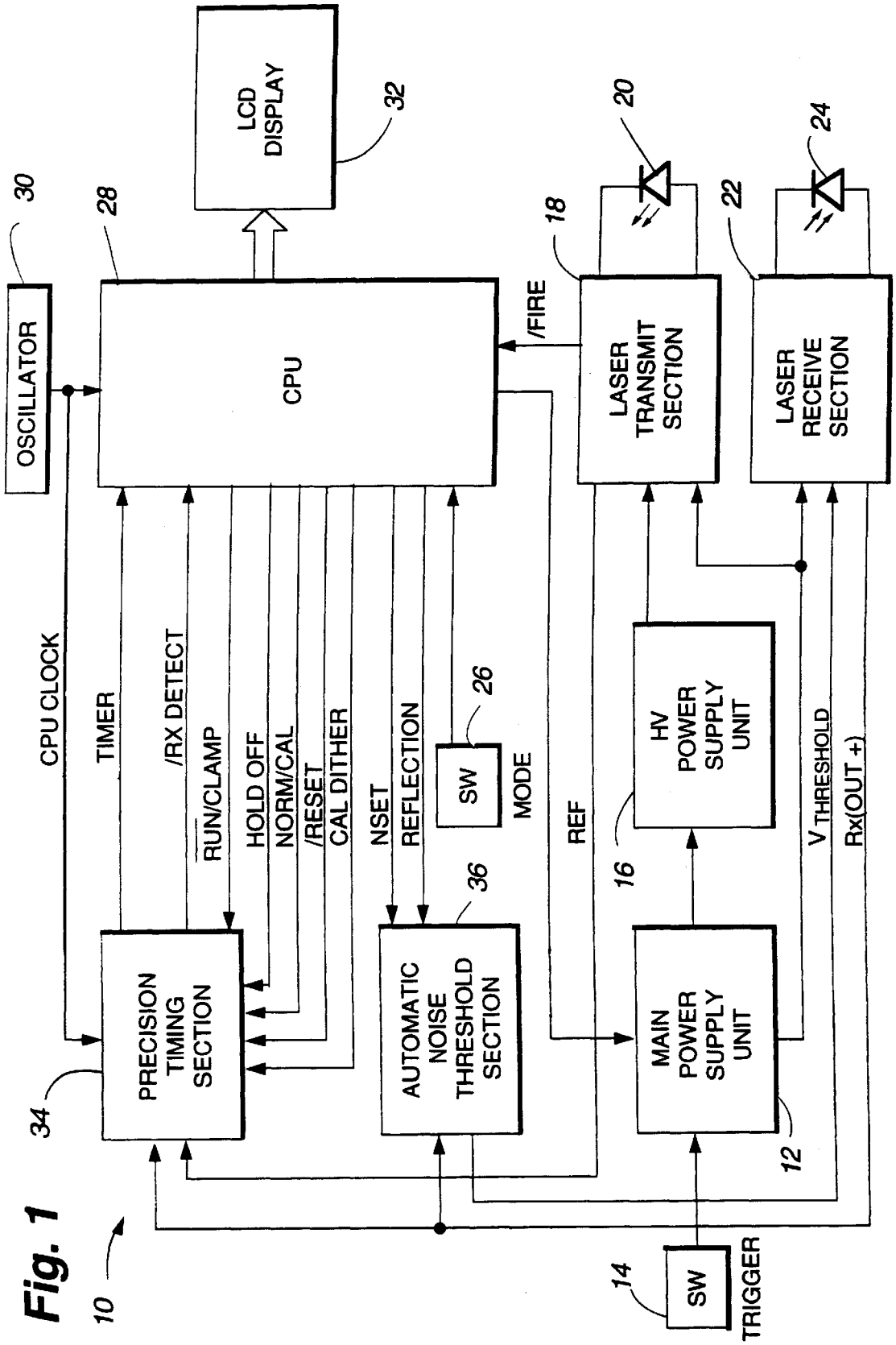

LCD DISPLAY
32
20
24
30
28
18
22
OSCILLATOR
CPU
/FIRE
LASER TRANSMIT SECTION
LASER RECEIVE SECTION
CPU CLOCK
TIMER
/RX DETECT
RUN/CLAMP
HOLD OFF
NORM/CAL
/RESET
CAL DITHER
NSET
REFLECTION
SW
26
MODE
REF
HV POWER SUPPLY UNIT
16
V THRESHOLD
Rx(OUT +)
36
PRECISION TIMING SECTION
AUTOMATIC NOISE THRESHOLD SECTION
MAIN POWER SUPPLY UNIT
12
34
14
SW
TRIGGER
10

Fig. 1

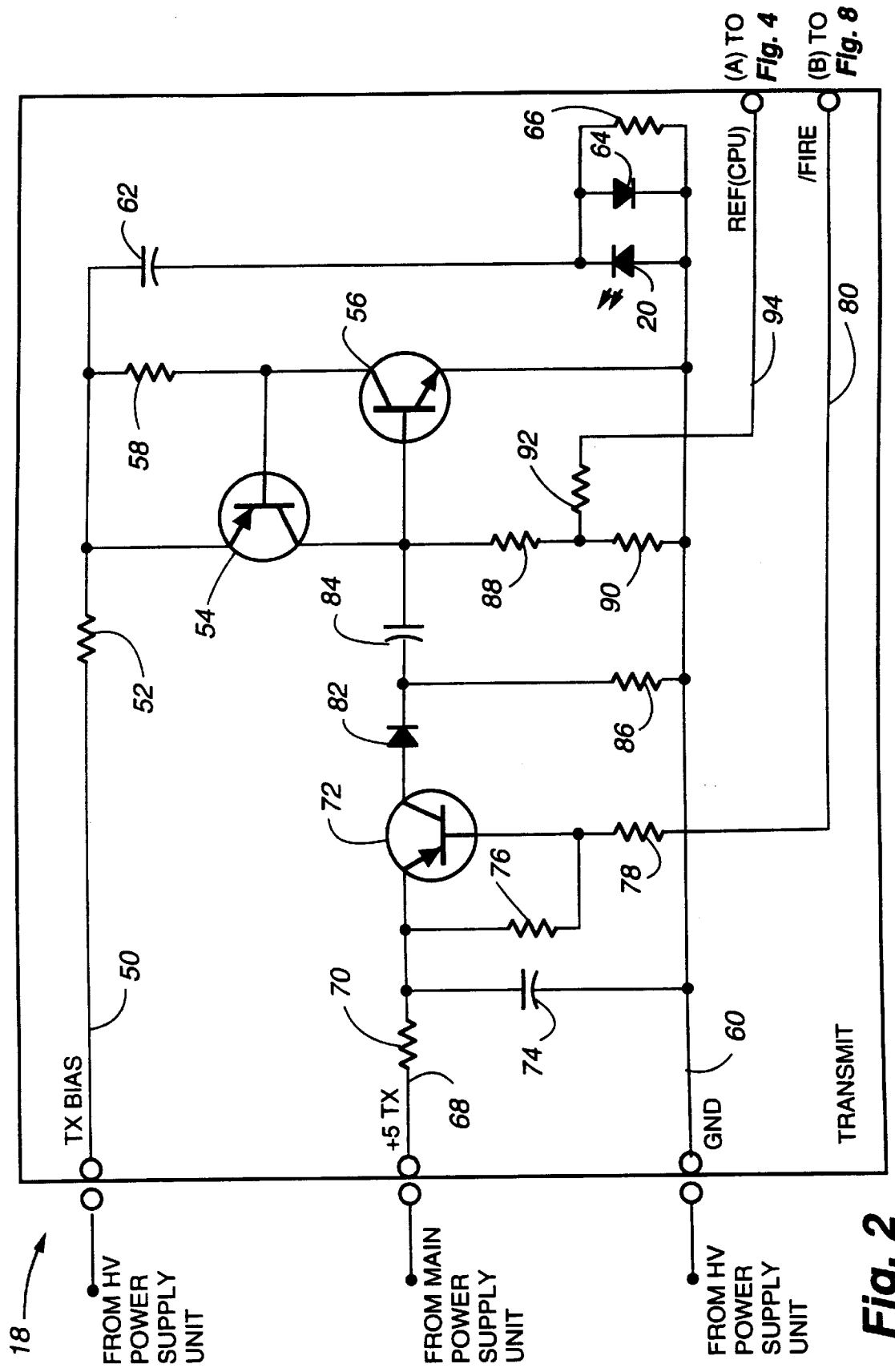

(A) TO Fig. 4
(B) TO Fig. 8
REF(CPU)
/FIRE
TRANSMIT
TX BIAS
+5 TX
GND
FROM HV POWER SUPPLY UNIT
FROM MAIN POWER SUPPLY UNIT
FROM HV POWER SUPPLY UNIT
18
20
50
52
54
56
58
60
62
64
66
68
70
72
74
76
78
80
82
84
86
88
90
92
94

Fig. 2

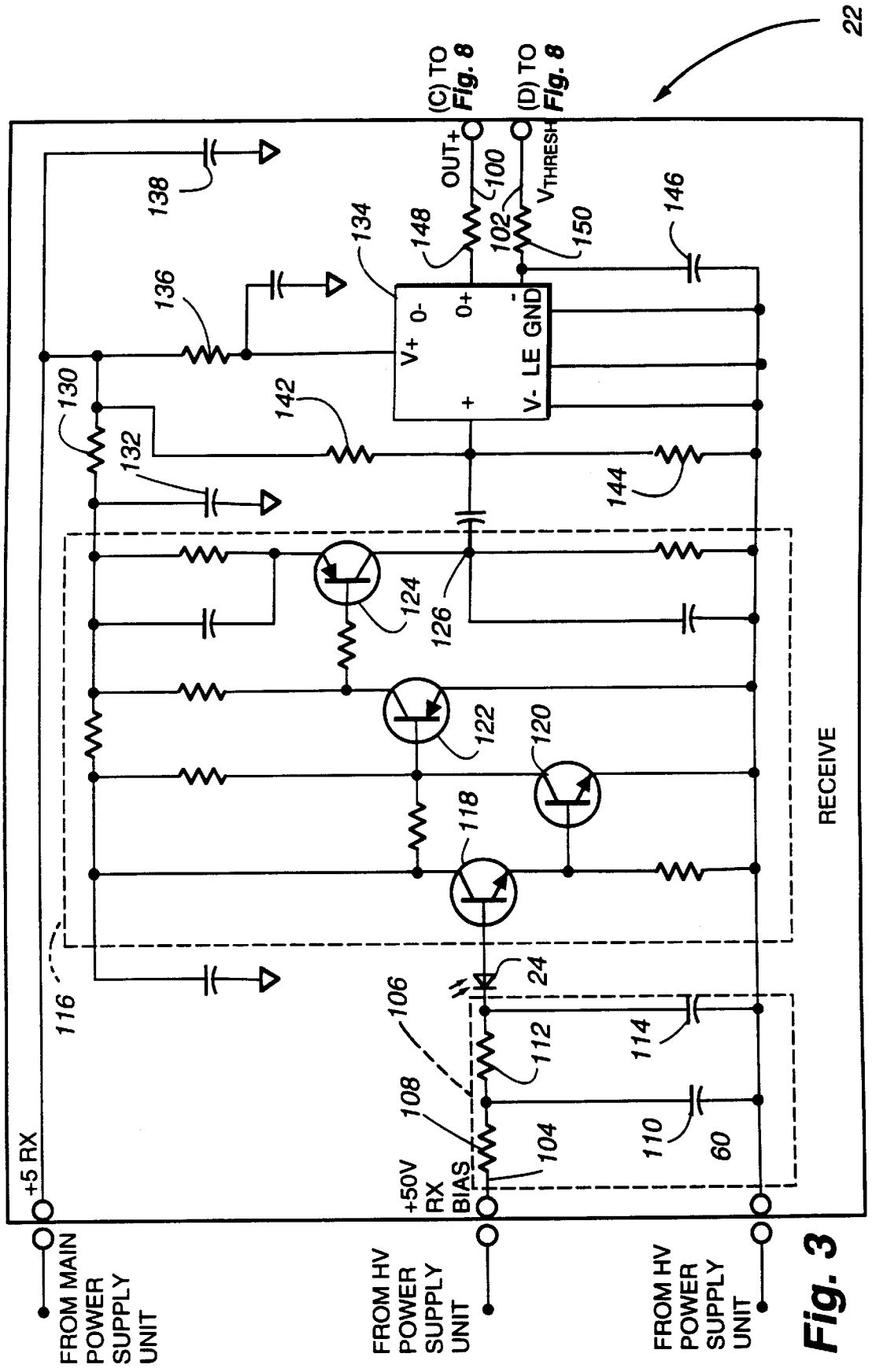

22
(C) TO Fig. 8
(D) TO Fig. 8
OUT+
VTHRESH
V+ 0- 0+ V- LE GND
+5 RX
+50V RX BIAS
RECEIVE
FROM MAIN POWER SUPPLY UNIT
FROM HV POWER SUPPLY UNIT
FROM HV POWER SUPPLY UNIT

Fig. 3

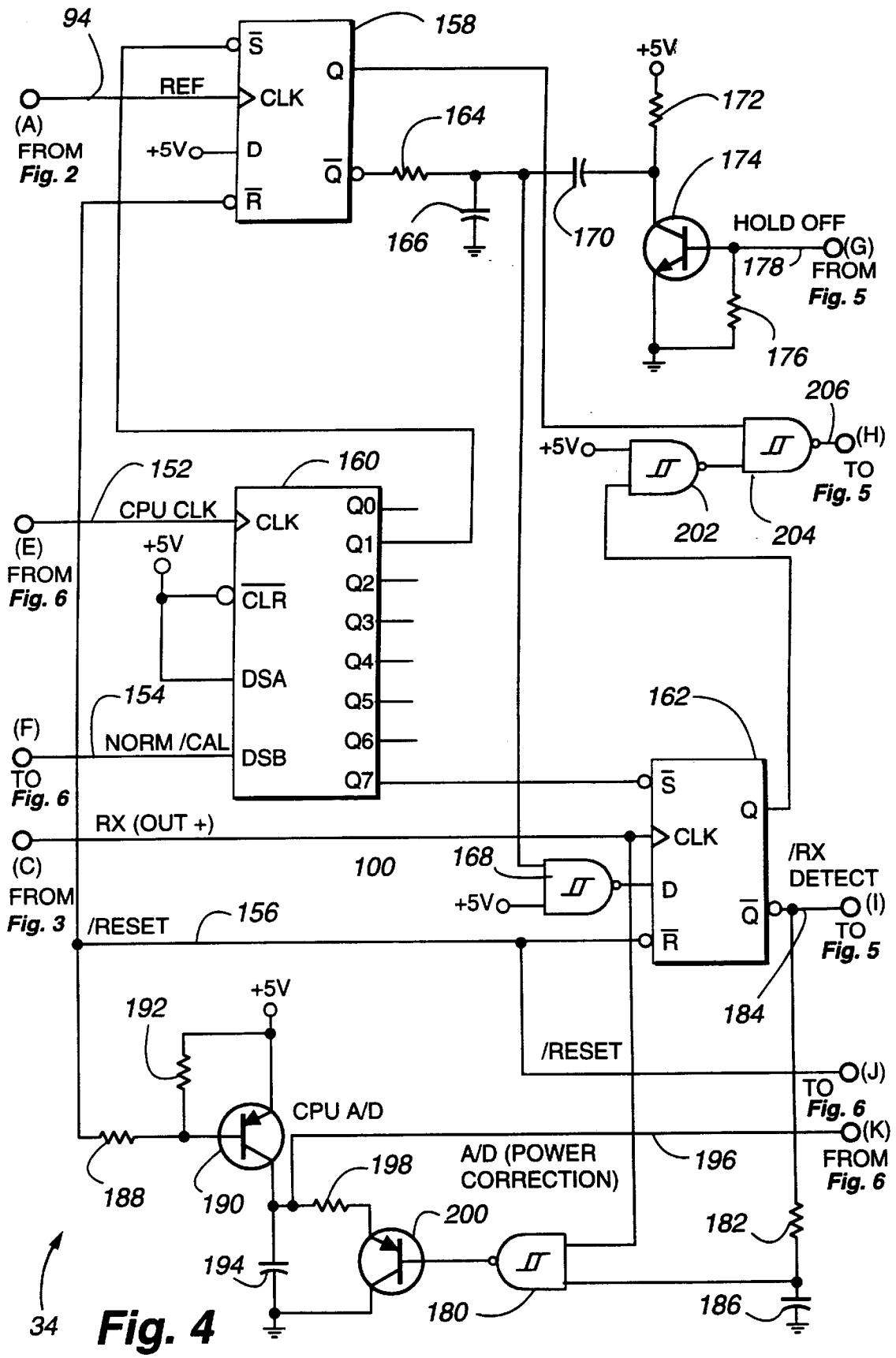

94
158
S
Q
REF
CLK
(A)
FROM
Fig. 2
+5V
D
Q
164
R
166
170
+5V
172
174
HOLD OFF
(G)
FROM
Fig. 5
178
176
206
(H)
TO
Fig. 5
+5V
202
204
152
160
CPU CLK
CLK
Q0
Q1
Q2
Q3
Q4
Q5
Q6
Q7
(E)
FROM
Fig. 6
+5V
CLR
DSA
154
162
(F)
TO
Fig. 6
NORM /CAL
DSB
S
Q
RX (OUT +)
CLK
(C)
FROM
Fig. 3
100
168
/RX
DETECT
(I)
TO
Fig. 5
+5V
D
/RESET
156
Q
R
184
+5V
192
/RESET
(J)
TO
Fig. 6
CPU A/D
(K)
FROM
Fig. 6
196
198
A/D (POWER
CORRECTION)
188
190
200
182
194
180
186
34

Fig. 4

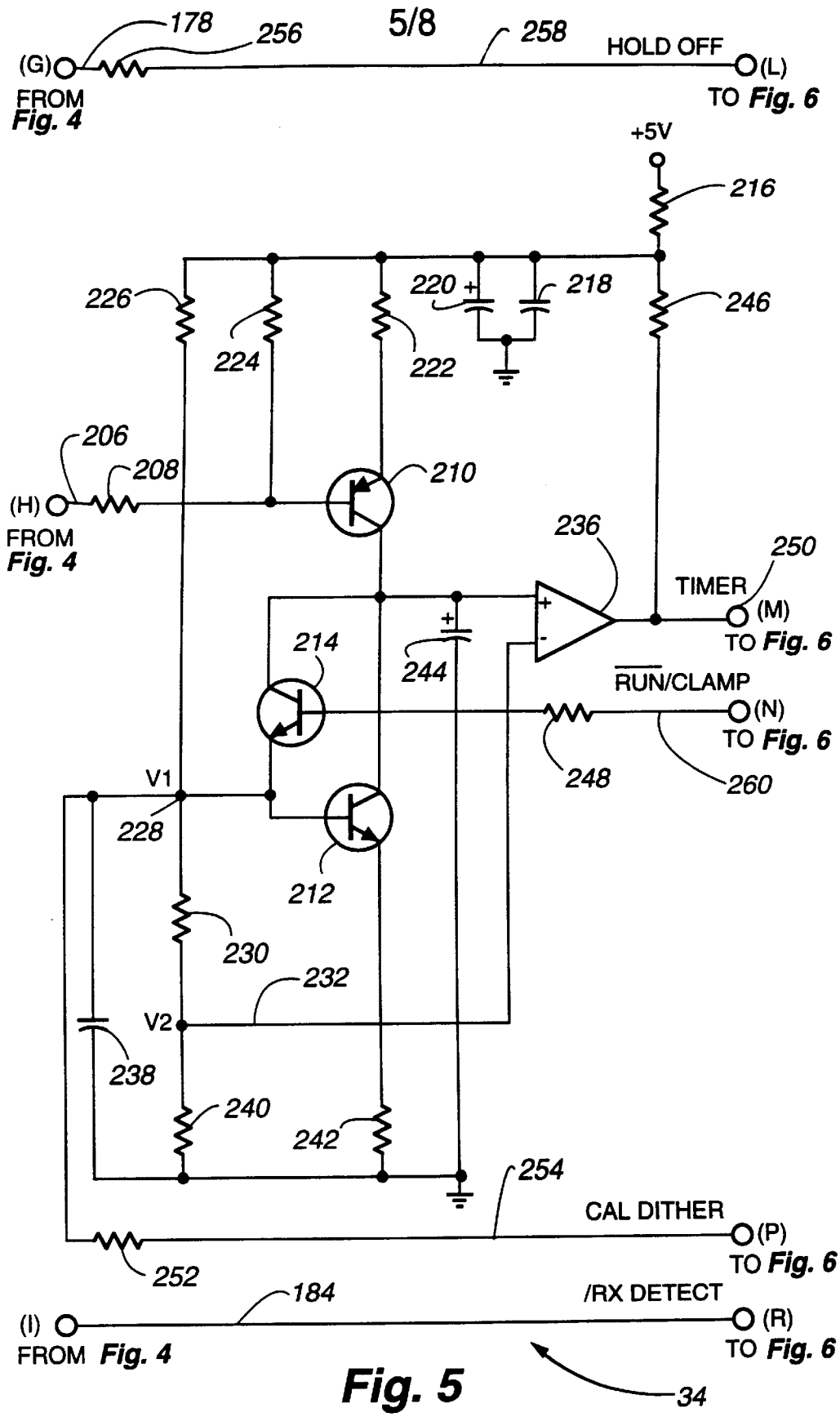

5/8
178
256
258
HOLD OFF
(G)
(L)
FROM Fig. 4
TO Fig. 6
+5V
216
226
220
218
246
224
222
206
208
210
(H)
FROM Fig. 4
236
250
TIMER
(M)
TO Fig. 6
214
244
RUN/CLAMP
(N)
TO Fig. 6
248
260
V1
228
212
230
232
V2
238
240
242
254
CAL DITHER
(P)
TO Fig. 6
252
184
/RX DETECT
(I)
(R)
FROM Fig. 4
TO Fig. 6
34

Fig. 5

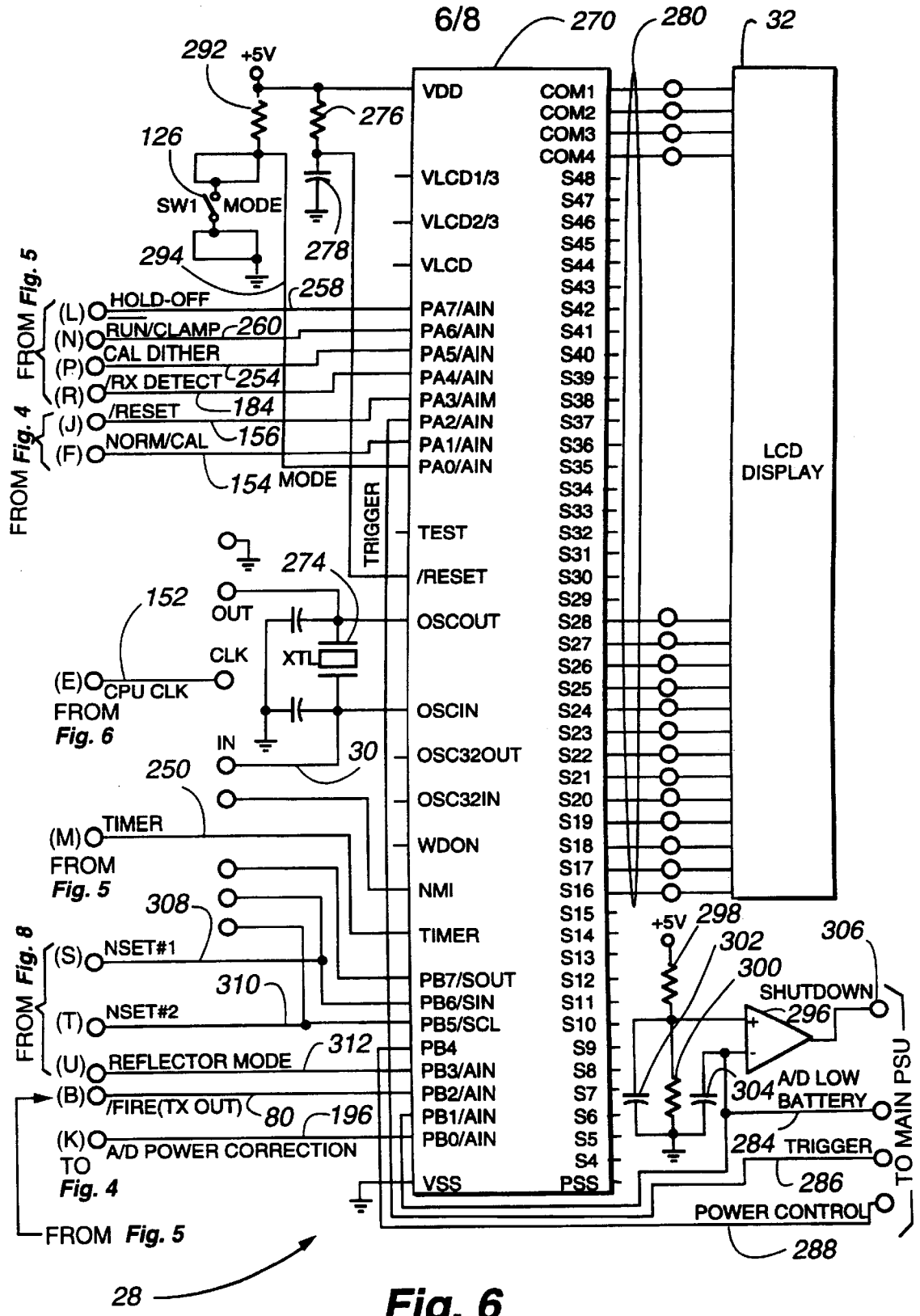

6/8
270
280
32
292
+5V
276
126
SW1
MODE
294
278
258
FROM Fig. 5
FROM Fig. 4
(L) HOLD-OFF
(N) RUN/CLAMP
260
(P) CAL DITHER
(R) /RX DETECT
254
(J) /RESET
184
(F) NORM/CAL
156
154 MODE
TRIGGER
274
152
OUT
CLK
XTL
(E) CPU CLK
FROM Fig. 6
IN
30
250
(M) TIMER
FROM Fig. 5
308
FROM Fig. 8
(S) NSET#1
310
(T) NSET#2
(U) REFLECTOR MODE
312
(B) /FIRE(TX OUT)
80
196
(K) A/D POWER CORRECTION
TO Fig. 4
FROM Fig. 5
28
VDD
VLCD1/3
VLCD2/3
VLCD
PA7/AIN
PA6/AIN
PA5/AIN
PA4/AIN
PA3/AIM
PA2/AIN
PA1/AIN
PA0/AIN
TEST
/RESET
OSCOUT
OSCIN
OSC32OUT
OSC32IN
WDON
NMI
TIMER
PB7/SOUT
PB6/SIN
PB5/SCL
PB4
PB3/AIN
PB2/AIN
PB1/AIN
PB0/AIN
VSS
COM1
COM2
COM3
COM4
S48
S47
S46
S45
S44
S43
S42
S41
S40
S39
S38
S37
S36
S35
S34
S33
S32
S31
S30
S29
S28
S27
S26
S25
S24
S23
S22
S21
S20
S19
S18
S17
S16
S15
S14
S13
S12
S11
S10
S9
S8
S7
S6
S5
S4
PSS
LCD DISPLAY
+5V
298
302
300
306
SHUTDOWN
296
304
A/D LOW BATTERY
284
TRIGGER
286
POWER CONTROL
288
TO MAIN PSU

Fig. 6

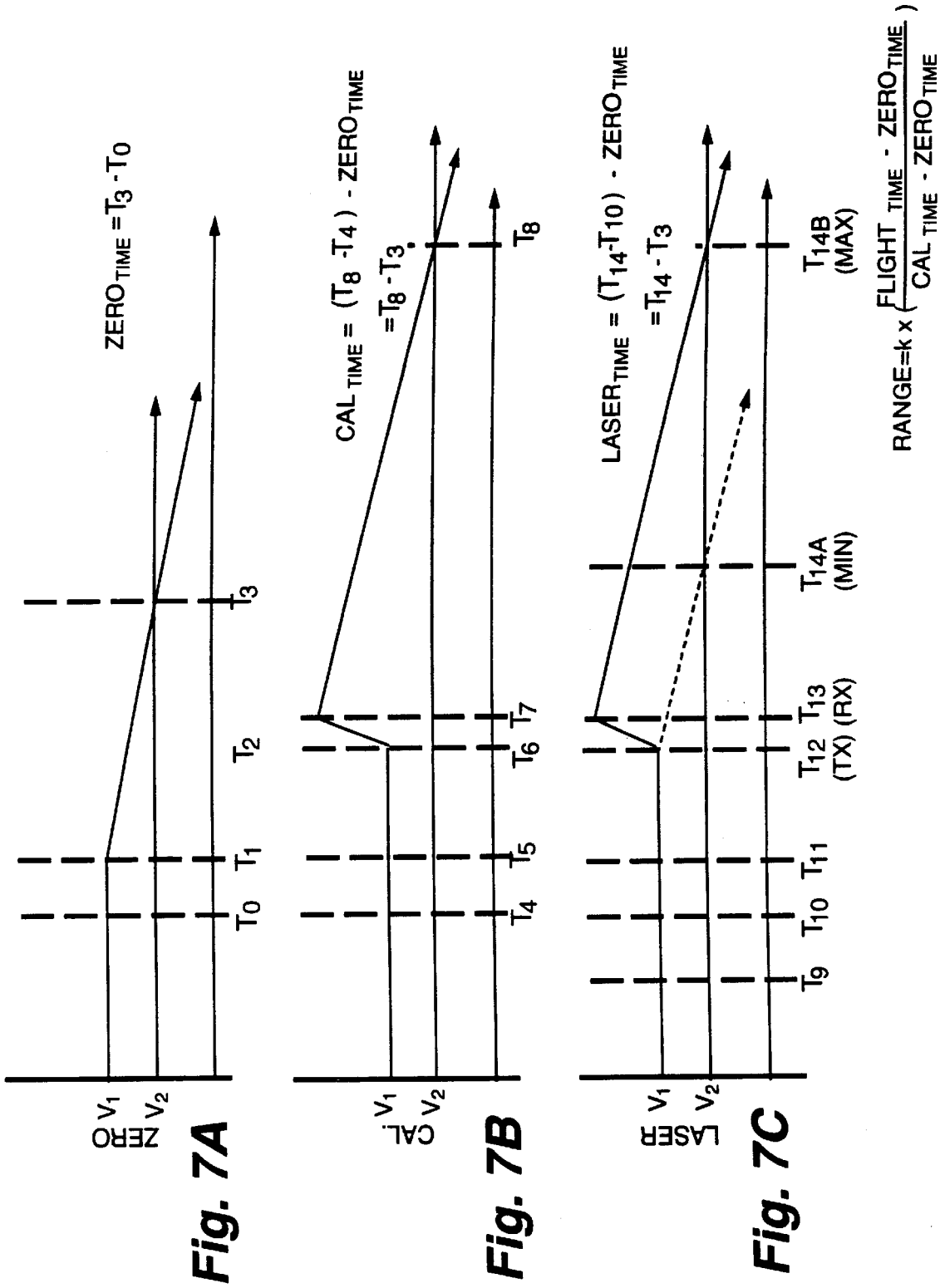


Fig. 7A

Fig. 7B

Fig. 7C

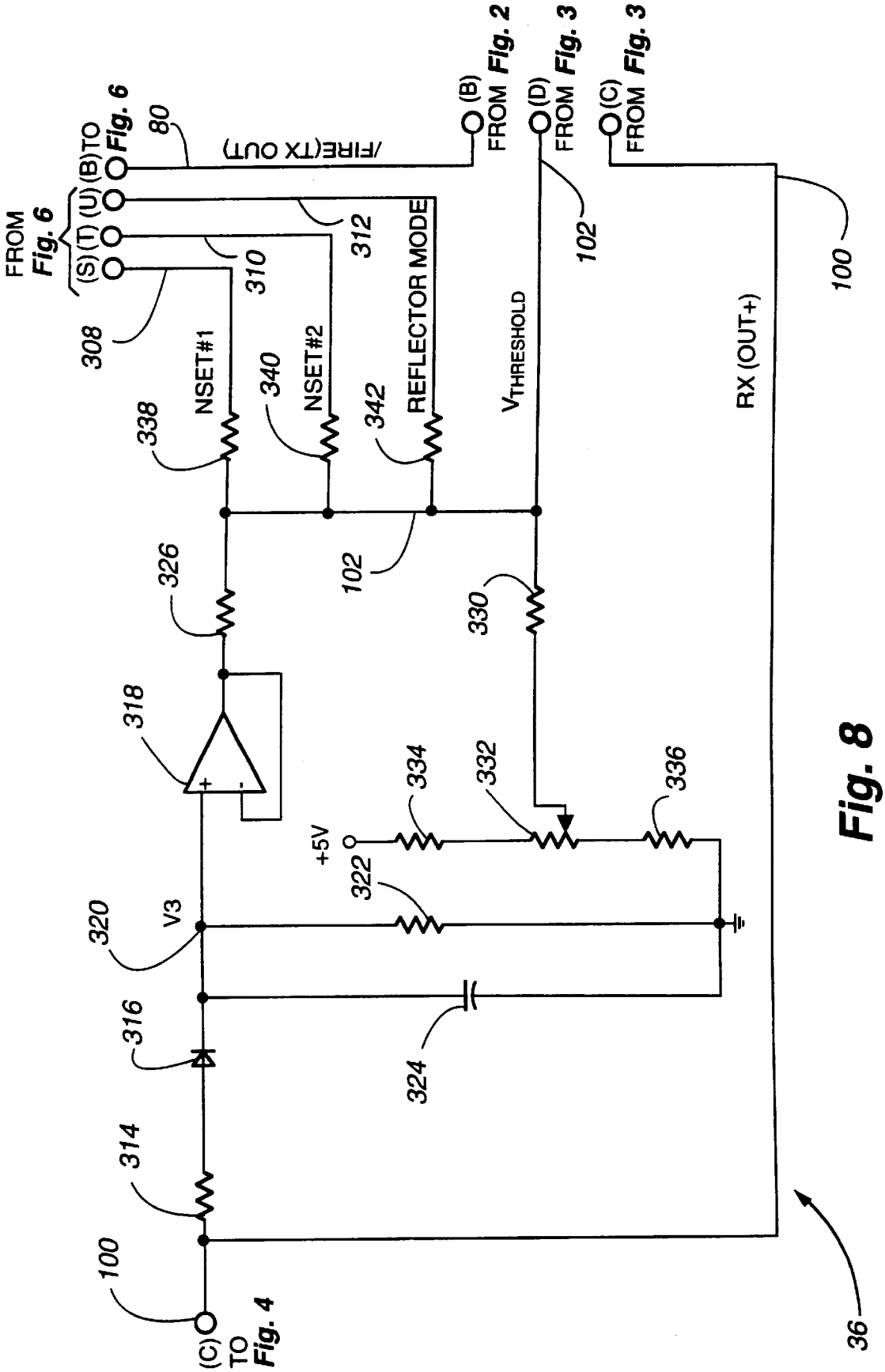

FROM Fig. 6
(S) (T) (U) (B) TO Fig. 6
80
/FIRE(TX OUT)
(B) FROM Fig. 2
(D) FROM Fig. 3
(C) FROM Fig. 3
308
310
312
NSET#1
NSET#2
REFLECTOR MODE
$V_{THRESHOLD}$
RX (OUT+)
100
102
338
340
342
326
330
318
334
332
336
+5V
322
320
V3
316
314
324
100
(C) TO Fig. 4
36

Fig. 8

SELF-CALIBRATING PRECISION TIMING CIRCUIT AND METHOD FOR A LASER RANGE FINDER

CROSS REFERENCE TO RELATED APPLICATIONS

The present application claims priority from and is a continuation of U.S. patent application Ser. No. 09/234,724 filed Jan. 21, 1999, (now U.S. Pat. No. 6,057,910), a continuation of U.S. patent application Ser. No. 08/918,396 filed Aug. 26, 1997 (now U.S. Pat. No. 5,880,821), a continuation of U.S. patent application Ser. No. 08/717,635 filed Sep. 23, 1996 (now U.S. Pat. No. 5,703,678), a continuation of U.S. patent application Ser. No. 08/375,941 filed Jan. 19, 1995 (now U.S. Pat. No. 5,574,552), each incorporated herein by reference, from which priority under 35 U.S.C. §120 is claimed and which are assigned to the assignee of the present application.

The present invention is related to those disclosed and claimed in U.S. patent applications Ser. No.: U.S. Pat. No. 5,652,651 for: "Laser Range Finder Having Selectable Target Acquisition Characteristics and Range Measuring Precision"; and [Attorney Docket No. 35014.8308] for: "Automatic Noise Threshold Determining Circuit and Method for a Laser Range Finder", all filed concurrently with U.S. patent application Ser. No. 08/375,941, from which priority under 35 U.S.C. §120 is claimed herein, all of which are assigned to the assignee of the present invention, Laser Technology, Inc., Englewood, Colo., the disclosures of which are hereby specifically incorporated by this reference.

BACKGROUND OF THE INVENTION

The present invention relates, in general, to the field of distance or range measuring equipment. More particularly, the present invention relates to a laser based range finder which may be inexpensively produced yet provides highly accurate precision range measurements of up to 1000 yards or more with a resolution of less than 1 yard. The laser range finder herein disclosed has a number of user selectable target acquisition and enhanced precision measurement modes which may be viewed on an in-sight display during aiming and operation of the instrument. Extremely efficient self-calibrating precision timing and automatic noise threshold circuits incorporated in the design provide a compact, low-cost, highly accurate and reliable ranging instrument for a multitude of uses.

Laser based distance and range measuring equipment have been used for a number of years to provide extremely accurate distance measurements to a remote target or object. A representative instrument is the Criterion™ 100 laser range finder developed and marketed by Laser Technology, Inc., assignee of the present invention. Although a highly accurate and reliable device, its great distance ranging capability and inherent complexity translates to a cost and form factor most suitable only for certain specific applications. A need therefore exists for a laser based range finder of perhaps more limited range, which can be economically manufactured as a rugged, compact unit to provide accurate distance measurement capabilities in other less stringent types of applications.

SUMMARY OF THE INVENTION

Herein disclosed is a precise, yet accurate and reliable laser range finder which may be economically produced and is adapted to individual portable use in a unit potentially

weighting less than a pound with an on-board battery based power supply. Moreover, the compact instrument herein provided has a number of user selectable target acquisition operational modes which may be invoked depending on the distance, type and reflectivity of the target being sighted.

Though the use of an in-sight display, distance or range information can be shown while the user may also view and select the instrument's mode of operation through successive actuations or a push button mode switch while simultaneously sighting the target object. A precision mode of operation may also be invoked in which an even more precise measurement to an object may be achieved following an initial measurement together with the visual indication of a "precision flag" on the in-sight display.

A highly precise range measurement is made possible through the use of a novel and efficient timing circuit which makes use of the instrument's internal central processing unit crystal oscillator. A likewise unique automatic noise threshold determining circuit allows for instrument operation with a low signal-to-noise ratio to optimize sensitivity and performance in conjunction with a processor based pulse discrimination procedure which, nevertheless assures accurate range measurements.

The unit herein disclosed can be utilized in a multitude of endeavors including such recreational activities as golf where it can be utilized to very accurately determine the distance to a flag or pin as well as to trees and other natural objects. The principles of the invention are further applicable to the design or a laser based "tape measure" where ranges can be precisely measured with resolutions of on the order of an inch or less.

Specifically disclosed herein is a self-calibrating, precision timing circuit and method for determining a range to a target based upon a flight time of a pulse toward the target. The circuit comprises means for initially establishing first and second reference voltage levels together with means for unclamping the second reference voltage level and means for allowing the second reference voltage level to then diminish at a first rate to the first reference voltage level. Further provided are means for storing a first reference time extending from the step or unclamping until the first and second reference voltage levels are determined to be equal. Means are also provided for then re-establishing the first and second reference voltage levels together with means for again unclamping the second reference voltage level. Additional means are provided for increasing the second reference voltage level at a second higher rate than the first rate for a predetermined period of time to establish a third reference voltage level together with means for then allowing the third reference voltage level to diminish at the first rate to the first reference voltage level at which time, a second reference time extending from the step of again unclamping until the first and third reference voltage levels are equal is additionally stored. The first and second reference voltage levels are again re-established and the second reference voltage level is further unclamped. Means are provided for again increasing the second reference voltage level at the second higher rate for a period of time related to the flight time of the pulse to the target to establish a fourth reference voltage level, together with means for then allowing the fourth reference voltage level to diminish at the first rate to the first reference voltage level. A third reference time extending from the unclamping of the second reference voltage level until the first and fourth reference voltage levels are equal is then stored and the range to the target may be computed as proportional to the quantity of the (third reference time minus the first reference time) divided by the quantity of the (second reference time minus the first reference time).

In a particular embodiment the establishing means may comprise a transistor switch for coupling a capacitor to a source of the second voltage while the unclamping means may comprise a second transistor switch for decoupling the capacitor from the second voltage source. The allowing means may comprise a third transistor switch coupling a resistor to the capacitor to bleed off the charge therefrom.

The means for increasing the second reference voltage level may comprise means for applying a charge to the capacitor at the second rate and the predetermined time period specified may be determined by reference to a crystal oscillator. In a particular embodiment, the second charging rate may be substantially 1000 times the first discharging rate.

DETAILED DESCRIPTION OF THE DRAWINGS

The foregoing and other features and objects of the present invention and the manner of attaining them will become more apparent and the invention itself will be best understood by reference to the following description of a preferred embodiment taken in conjunction with the accompanying drawings, wherein:

FIG. **1** is a simplified logic block diagram of a laser range finder in accordance with the present invention illustrating the significant functional aspects thereof, inclusive of a laser signal transmitting and receiving section, central processing unit and the precision timing and automatic noise threshold sections thereof;

FIG. **2** is a detailed schematic diagram of the laser transmit section of FIG. **1** illustrating, inter alia, the laser signal producing diode and the associated driving and reference signal producing circuitry;

FIG. **3** is an additional detailed schematic diagram of the laser receive section of FIG. **1** illustrating, inter alia, the laser signal receiving diode, transimpendance amplifier and the precision comparator for establishing the $V_{threshold}$ and RX(Out+) signals for the precision timing and automatic noise threshold circuits;

FIGS. **4** and **5** are further detailed schematic diagrams of the precision timing section of the laser range finder of FIG. **1** illustrating the circuit nodes for establishing the voltages V_1 and V_2 during the zero, calibration ("CAL") and laser firing phases of operation;

FIG. **6** is an additional detailed schematic diagram of the central processing unit ("CPU") portion of the laser range finder of FIG. **1** illustrating the CPU, associated oscillator and the in-sight liquid crystal display ("LCD") for displaying measured distances to an operator of the laser range finder in addition to the various signals for operative association with the precision timing and automatic noise threshold sections thereof;

FIGS. 7A, 7B and 7C are individual graphic representations of the voltages V_1 and V_2 of certain of the precision timing section circuit nodes during the zero, calibration and laser firing phases of operation from which the values $Zero_{TIME}$, Cal_{TIME} and $Laser_{TIME}$ are derived to enable rapid and accurate calculation of the distance to an object from the laser range finder; and

FIG. **8** is a final detailed schematic diagram of the automatic noise threshold section of the laser range finder of FIG. **1** illustrating the various components thereof as well as the signals coupling the same to the laser receive section and CPU.

DESCRIPTION OF A PREFERRED EMBODIMENT

With reference now to FIG. **1**, a logic block diagram of a laser range finder **10** in accordance with the present invention is shown. The laser range finder **10** includes, in pertinent part, a main power supply unit ("PSU") **12** as operatively controlled by a trigger switch **14**. The main power supply unit **12** is coupled to a high voltage ("HV") power supply unit **16** for supplying operating power in conjunction with the main power supply unit **12** to a laser transmit section **18**.

The laser transmit section **18** activates a laser emitting diode **20** for directing a laser signal toward an object in the operation of the laser range finder **10**. The laser transmit section **18** also supplies a /FIRE signal to the central processing unit ("CPU") section **28** as will be more fully described hereinafter.

The main power supply unit **12** also supplies operating power to a laser receive section **22** which further has an input a signal generated by a laser receiving diode **24** as the laser signal emitted from the laser emitting diode **20** is reflected from an object back thereto. The laser receive section **22** supplies a $V_{threshold}$ signal and RX(OUT+) signal to an automatic noise threshold section **36** and a precision timing section **34** both of which will be described in more detail hereinafter.

The CPU section **28** receives as one input a signal from a mode switch **26** by means of which an operator can change the operating mode and functional operation of the laser range finder **10**. An oscillator **30** supplies a clocking signal to the CPU section **28** as well as to the precision timing section **34**. The CPU section **28** provides an output indicative of the distance from the laser range finder **10** to an object as sighted through a viewing scope thereof on an in-sight liquid crystal display ("LCD") **32**.

The precision timing section **34** provides a number of signals to the CPU section **28** including a TIMER and /RX DETECT signals as shown and receives a RUN/CLAMP signal back therefrom. The CPU section **28** provides a number of signals to the precision timing section **34** including a HOLD OFF, NORM/CAL, /RESET, and a CAL DITHER signal. The automatic noise threshold section **36** also receives a number of inputs from the CPU section **28** including a number of noise set ("NSET") signals and a REFLECTION MODE signal to operatively control its function.

With reference additionally now to FIG. **2**, the laser transmit section **18** is shown in more detail. The laser transmit section **18** receives a transmit ("TX") BIAS signal on supply line **50** of approximately 110 to 140 volts for application through resistor **52** to the emitter of transistor **54**. The emitter of transistor **54** is coupled to its base by means of a resistor **58** which also couples the collector of transistor **56** to resistor **52**. The emitter of transistor **56** is connected to circuit ground on ground line **60**. A capacitor **62** couples the emitter of transistor **54** to the cathode of the laser emitting diode **20** which has its anode also connected to circuit ground **60**. An additional diode **64** is coupled in parallel with the laser emitting diode **20** having its anode connected to the cathode of the laser emitting diode **20** and its cathode connected to circuit ground **60**. A resistor **66** is placed in parallel with the laser emitting diode **20** and the diode **64**.

A source of +5 volts is also received by the laser transmit section **18** on supply line **68** through resistor **70**. Resistor **70** is coupled to the emitter of transistor **72** as well as to circuit ground **60** through a capacitor **74**. A resistor **76** couples the emitter of transistor **72** to its base which is coupled through resistor **78** to line **80** for supplying a /FIRE signal to the CPU section **28** (shown in FIG. **1**).

An additional diode **82** has its anode connected to the collector of transistor **72** and its cathode coupled to circuit

ground **60** through resistor **86**. A capacitor **84** couples the cathode of diode **82** to the common connected collector of transistor **54** and base of transistor **56**. The common connected collector of transistor **54** and base of transistor **56** is coupled through a voltage divider network comprising resistor **88** and resistor **90** to circuit ground. A resistor **92** coupled between resistor **88** and resistor **90** provides a REF signal on line **94** for application to the precision timing section **34** (shown in FIG. **1**).

With reference additionally now to FIG. **3**, the laser receive section **22** is shown in more detail. The output signals of the laser receive section **22** are the signals RX(OUT+) and $V_{threshold}$ provided on lines **100** FIGS. **4**, **8**; and **102** FIG. **8** respectively for application to the precision timing section **34** and automatic noise threshold section **36** as previously shown in FIG. **1**. A source of +50 volts providing a receive ("RX") BIAS signal is input to the laser receive section **22** from the HV power supply unit **16** on supply line **104**. A low pass filter network **106** comprising resistors **108** and **112** in conjunction with capacitors **110** and **114** couples the supply line **104** to circuit ground **60** to provide a bias signal to the cathode of the laser receiving diode **24**. The laser receiving diode **24** has its anode connected to the base of transistor **118** which, in conjunction with transistor **120**, **122**, and **124** comprises a transimpedance amplifier **116** providing an output on node **126** which is capacitively coupled to the "+" input of a precision comparator **134**. A source of +5 volts is input to the laser receive section **22** from the main power supply unit **12** (shown in FIG. **1**) for input to the transimpedance amplifier **116** through a low pass filter comprising resistor **130** and capacitor **132**. The +5 volt RX supply voltage is also coupled to the v+ input of the precision comparator **134** through resistor **136** and is coupled to circuit ground through capacitor **138**. The "+" input of the precision comparator **134** is connected between the plus 5 volt RX voltage source and circuit ground **60** through the node intermediate resistor **142** and resistor **144**.

The precision comparator **134** which may, in a preferred embodiment, comprise a MAX 913 low power precision transistor-transistor logic ("TTL") comparator available from Maxim Integrated Products, Inc., Sunnyvale, Calif., has its "v−", "LE" and ground ("GND") inputs connected to circuit ground **60** as shown. A capacitor **146** couples the "−" output of the precision comparator **134** to circuit ground **60** as shown. The "O+" output of the precision comparator **134** is supplied through a resistor **148** to line **100** to provide the RX(OUT+) signal while the "−" output of the precision comparator **134** is supplied through resistor **150** to line **102** to provide the $V_{threshold}$ signal.

With reference additionally now to FIG. **4**, a portion of the precision timing section **34** (shown in FIG. **1**) is illustrated. A CPU clock ("CLK") signal is input to the precision timing section **34** on line **152** to the CLK input of a serial in/parallel out shift register **160** from the oscillator **30** as previously shown in FIG. **1**. An additional input to the shift register **160** is received on line **154** comprising a NORM/CAL signal from the CPU section **28** to the data set B ("DSB") input thereof. The active low clear ("$\overline{CLR}$") input and DSA input are held high as shown.

An additional input to the precision timing section **34** is received from the CPU section **28** (shown in FIG. **1**) on line **156** comprising a /RESET signal for input to the reset ("$\overline{R}$") inputs of D type flip-flop **158** and flip-flop **162**. The $\overline{Q}$ output of flip-flop **158** is supplied as one input to an invertor comprising a portion of a NAND Schmitt trigger **168** through a low pass filter comprising resistor **164** and capacitor **166** as shown. The remaining input to the invertor **168** is connected to a source of +5 volts.

A resistor **172** couples a source of +5 volts to the collector of transistor **174** having its emitter coupled to circuit ground. The collector terminal of transistor **174** is coupled through capacitor **170** to the input of the invertor **168** coupled to the $\overline{Q}$ output of flip-flop **158**. Transistor **174** has its based coupled to circuit ground through resistor **176** and receives a HOLD OFF signal on node **178** received from the CPU section **28**.

The flip-flop **158** receives an input to its CLK terminal on line **94** comprising the REF output signal from the laser transmit section **18** (shown in FIG. **1**). Its data ("D") input is coupled to a source of +5 volts and the Q1 output of the shift register **160** is provided to the active low set ("$\overline{S}$") input as shown. The Q output of flip-flop **158** is supplied as one input to a transmit gate **204** having its other input coupled to the output of an invertor comprising an additional NAND Schmitt trigger **202**. Invertor **202** has one input connected to a source of +5 volts and another input connected to the Q output of flip-flop **162**. Flip-flop **162** has its $\overline{S}$ input coupled to the Q7 output of shift register **160** and its D input connected to the output of invertor **168**. The $\overline{Q}$ output of flip-flop **162** is supplied on line **184** to comprise a /RX DETECT signal for input to the CPU section **28** (shown in FIG. **1**). The flip-flop **162** has its CLK input connected to line **100** for receiving the RX(OUT+) signal from the laser receive section **22** (shown in FIG. **1**) which is also supplied as one input to NAND Schmitt trigger **180**. The other input of NAND Schmitt trigger **180** is connected to line **184** through resistor **182** and coupled to circuit ground through capacitor **186**. The output of Schmitt trigger **180** is supplied to the base electrode of transistor **200** which has its collector terminal coupled to circuit ground. Line **196**, comprising an analog-to-digital ("A/D") POWER CORRECTION signal is supplied to the emitter terminal of transistor **200** through resistor **198** as well as to the collector terminal of transistor **190** which is coupled to circuit ground through capacitor **194**. The /RESET signal on line **156** is supplied to the base terminal of transistor **190** through resistor **188**. A source of +5 volts is connected to the emitter of transistor **190** as well as through resistor **192** to the base of transistor **190** to provide an operating bias.

Referring additionally now to FIG. **5**, the remaining portion of the precision timing section **34** (shown in block form in FIG. **1**) is illustrated. The HOLD OFF signal output from CPU section **28** to the precision timing section **34** is supplied on line **258** through resistor **256** to node **178** for input to the base of transistor **174** (shown in FIG. **4**).

The output of transmit gate **204** appearing on node **206** is supplied through resistor **208** to the base terminal of transistor **210**. A source of +5 volts is supplied to the emitter terminal of transistor **210** through the series connection of resistor **216** and resistor **222**. The node intermediate resistors **216** and **222** is coupled to circuit ground through the parallel combination of capacitors **218** and **222** as well as to the output of comparator **236** through resistor **246** to provide a TIMER signal on line **250** for input to the CPU section **28** as will be more fully described hereinafter. The source of +5 volts is also connected to the base terminal of transistor **210** through the series connection of resistors **216** and **224**. A V_1 node **228** at the common connected base of transistor **212** and emitter of transistor **214** is coupled through a source of +5 volts through resistor **216** and resistor **226**. Node **228** is connected through resistor **230** to V_2 node **232** which, in turn, is connected to circuit ground through resistor **240**. A capacitor **238** couples V_1 node **228** to circuit ground. V_2

node **232** is connected to the "−" input of comparator **236**. V_1 node **228** is connected to line **254** from the CPU section **28** (shown in FIG. **1**) to receive the CAL DITHER signal through resistor **252**.

The collector terminal of transistor **210** is coupled to the collector terminals of transistors **212** and **214** as well as to the "+" terminal of comparator **236** which, in turn, is coupled to circuit ground through capacitor **244**. A $\overline{\text{RUN}}$/CLAMP signal output from the CPU section **28** (shown in FIG. **1**) is furnished on line **260** through resistor **248** for input to the base terminal of transistor **214**.

With reference additionally now to FIG. **6**, the CPU section **28** is shown in greater detail. The CPU section **28** comprises, in pertinent part, a microcomputer **270** which may, in a preferred embodiment, comprise a ST6240 device. An 8 megaHertz ("MHz") crystal **274** forms a portion of the oscillator **30** for providing an oscillator ("OSCIN") and oscillator out ("OSCOUT") signal to the microcomputer **270** as well as supplying a CPU CLK signal on line **152** for input to the precision timing section **34** as previously described. The VDD input of microcomputer **270** is coupled to a source of +5 volts and the /RESET input thereof is held high through pull up resistor **276** which is coupled to circuit ground through capacitor **278**. Output from the microcomputer **270** is taken on a display bus **280** comprising the communication ("COM") lines COM **1**–COM **4** and S**16**–S**28** lines for input to the LCD display **32**.

An A/D LOW BATTERY signal, a TRIGGER signal, and a POWER CONTROL signal are input to the microcomputer **270** on lines **284**, **286**, and **288** respectively. The A/D LOW BATTERY signal on line **284** is also supplied to the "−" input of comparator **296** which is coupled to circuit ground through capacitor **304**. The "+" input of comparator **296** is coupled to a source of +5 volts through resistor **298** which is also coupled to circuit ground through the parallel combination of resistor **300** and capacitor **302**. The output of comparator **296** appearing on line **306** provides a SHUTDOWN signal for the laser range finder **10** in the event the onboard battery voltage drops below a predetermined limit.

The microcomputer **270** supplies the HOLD OFF signal on line **258**, the $\overline{\text{RUN}}$/CLAMP signal on line **260**, the CAL DITHER signal on line **254**, the /RESET signal on line **156** and the NORM/CAL signal on line **154** for input to the precision timing section **34** as has been previously described. The microcomputer **270** receives as outputs from the precision timing section **34** the /RX DETECT signal on line **184** and the TIMER signal on line **250**. Additional inputs to the microcomputer **270** are the /FIRE signal on line **80** from the laser transmit section **18** (shown in FIG. **1**) as well as the A/D POWER CORRECTION signal on line **196** from the precision timing section **34** (as shown in FIG. **4**). A MODE input signal on line **294** is received from the mode switch **126** which is otherwise held to a +5 volts through resistor **292**. Microcomputer **270** supplies an NSET**1** and NSET**2** signal on lines **308** and **310** respectively as well a REFLECTION MODE signal on line **312** for input to the automatic noise threshold section **36** (as shown in FIG. **1**).

In overall operation, a reference signal (REF) on line **94** is generated by the laser transmit section **18** (shown in FIG. **2**) when the laser range finder **10** is fired by placing a current pulse through the laser emitting diode **20** in response to manual actuation of the trigger switch **14**. The REF signal on line **94** is derived from the current placed through the laser emitting diode **20** and not from the light pulse itself and is sufficiently precise for accurately indicating the time of the laser firing. The REF signal is ultimately input to the CLK input terminal of flip-flop **158**, which has its Q output coupled to the transmit gate **204**, which then turns on the current switch comprising transistor **210**, and starts charging the capacitor **244**. When the receive pulse (RX(OUT+) on line **100** comes back from the laser receive section **22** (shown in FIG. **3**), it triggers the flip-flop **162** at its CLK input. Flip-flop **162** has its Q output coupled to the input of invertor **202** which then shuts the transmit gate **204** off, stopping the current pulse. At this point, a constant current sink discharges capacitor **244**. In this manner, capacitor **244** is charged up with a relatively large current (on the order of 10 milliamps), and later discharged with a small current (on the order of 10 microamps) applied over the entire flight time of the laser pulse from its firing from the laser emitting diode **20** to its reflection from a target back to the laser receiving diode **24**. Because the laser range finder **10** is intended for a shorter maximum range than other laser based range finding instruments, the use of this technique doses not require a separate counting oscillator followed by an interpolation operation and the entire flight time is essentially stretched by a factor of 1000 and then the stretched result is counted. By charging capacitor **244** at a fast rate and then discharging it and then monitoring the time it takes to discharge, the flight time is expanded so that the slower clock in the CPU section **28** can then count it accurately. The microcomputer **270** utilized in the CPU section **28** has a 1.5 microsecond resolution and, because the incoming flight time has been expanded by a factor of 1,000 on the input side to the precision timing section **34**, it is the equivalent of a 1.5 nanosecond resolution, which corresponds to a measurement resolution for the laser range finder **10** of on the order of nine inches. Therefore, given that the laser range finder **10** is intended to be a one-yard instrument with a nine-inch resolution, sufficient resolution is provided to be able to measure distances up to a thousand yards to a one-yard accuracy.

The precision timing section **34** of the laser range finder **10** has three distinct modes of operation including a zero calibration, fixed pulse width calibration and laser measurement function as will be more fully described hereinafter. The portion of the precision timing section **34** comprising transistors **210**, **214**, and **212** (shown in FIG. **5**) is the essence of the integrating flight time expander. Transistor **210** functions as a current switch which is turned on for the duration of the laser flight time in the laser mode of operation and is also turned on for the duration of whatever calibration pulse is placed into it during the calibrate mode. In the latter instance, a calibration pulse is supplied by the shift register **160** via flip-flop **158** and the start and end of the calibration pulse is gated via transmit gate **204** to actually turn the transistor **210** on and off in order to function as a current source, typically sourcing 10 milliamps of current. It should be noted that prior to turning transistor **210** on, transistor **214** must first be turned off and, when the system is in the reset state ready to start the whole measurement sequence, transistor **210** is off. Transistor **212**, which is the current sink in the system, is always on, and typically sinks on the order of 10 microamps of current. In the reset condition, transistor **214** is on, and that clamps the voltage at the top plate of capacitor **244** to a voltage level designated a V**1** at node **228**. A voltage V**2** is defined as the voltage at node **232** at the "−" input of comparator **236**. It should also be noted that a metal oxide semiconductor field effect transistor ("MOSFET") may be utilized for transistor **40** and would exhibit a much lower offset than the bipolar device shown. However, due to the lower cost of bipolar transistors and the fact that any offset cancels during the processing of the signal, a bipolar transistor is entirely adequate for this purpose.

When transistor **214** is on, the voltage on the positive plate of capacitor **244** is clamped to voltage **V1**, plus a fixed offset due to the transistor **210**, which is small and typically on the order of 50 millivolts. During the zero calibration function, transistor **214** is turned on by holding the $\overline{\text{RUN}}$/CLAMP signal on line **260** high, thereby applying a positive current to its base through resistor **248**. To initiate the zero calibration, the TIMER signal on line **250** is asserted and supplied to the microcomputer **270** of the CPU section **28**. Utilizing the ST6240 unit shown in FIG. **6**, when the microcomputer TIMER pin is held high, the device is counting. Conversely, the microcomputer stops counting when the pin is allowed to go low. In operation, the output comparator **236**, determines whether or not the voltage at the top plate of capacitor **244** is greater or less than **V2**, and its output determines whether the TIMER pin on the microcomputer **270** is high or low. In the normal reset condition, the output of the comparator **236** is high, which means the time is active. In sequence, the microcomputer **270** initiates the TIMER function and then turns off transistor **214** by lowering the control signal $\overline{\text{RUN}}$/CLAMP on line **260**, to unclamp capacitor **244**. Capacitor **244** then starts discharging towards zero due to the current being drained out of it via transistor **212** at a rate of about ten microamps. When it has discharge such that the charge removed drops the voltage **V1** at node **228** to the level of **V2**, the output of the comparator **236** changes state to stop the TIMER function. (In the particular embodiment shown, **V1** is typically on the order of 1.0 volts and **V2** is about 0.9 volts.) The microcomputer **270** of the CPU section **28** now has a count value that relates to the amount of time it takes for capacitor **244** to discharge from **V1** down to **V2**. This process is repeated several times and the result is averaged. Typically ten iterations may be performed with the results accumulated and an average time computed.

As shown particularly with respect to FIG. **5**, the CAL DITHER signal on line **254** is applied to the base terminal of transistor **212** and is utilized during both the zero calibration and fixed pulse width calibration times and incorporates a relatively high value resistor **252**. The CAL DITHER signal allows for the introduction of a deliberately controlled change in the discharge current in order that the resultant count will vary slightly such that when the total counts are averaged together, a finer resolution is produced than would be the case merely using a fixed current to get the same count value. An adjustment of one part in about a thousand is provided during the zero calibration and fixed pulse width calibration modes because the finite resolution of the microcomputer **270** timer otherwise provides discreet timing intervals of 1.5 nanoseconds which would only provide distance measurement resolution of approximately one yard. In operation, the zero calibration count in the microcomputer **270** will typically be about 150 while in the fixed pulse width calibration mode it will be on the order of 900. The flight time count during the laser mode of operation can be anything from close to the zero calibration value to about 4500.

For example, during the zero calibration mode, the count value in the microcomputer **270** might be 150 but there is no way of knowing just how close the count actually is to 149 to 151. By utilizing the CAL DITHER signal to force the count over a couple of count boundaries (for example: 150, 150, 150, 151, 151, 152) the resolution of the counter may be effectively raised by a factor of two without having to utilize additional fine counters. In the embodiment shown, the resultant resolution is sufficient to maintain calibration to plus or minus one yard over a range of one thousand yards or less. Although implementations may vary, the CAL DITHER signal may be held high for five out of ten pulses and low for the remainder to provide the foregoing resolution enhancement.

Due to the fact that the actual laser flight time varies due to noise in the laser pulses and variability in target aiming, there is generally enough scatter in the measured laser flight time such that it covers more than one clock boundary and so will automatically average to a higher resolution through the use of the precision timing section **34** without invoking the CAL/DITHER function in the laser mode of operation.

With reference additionally now to FIGS. **7A**, **7B** and **7C**, the operation of the precision timing section **34** is shown in the zero calibration, fixed pulse width calibration and laser measurement function modes of operation respectively. In its normal state, the voltage on the top plate of capacitor **244** is clamped at **V1**, and at a time T_0, the precision timing section **34** will initiate the TIMER by changing the output state of comparator **236** to the logic high state. After a very short fixed number of instructions later shown as T_1, the clamp transistor **214** will be turned off and the voltage on capacitor **244** will begin discharging slowly until that voltage crosses **V2** at time T_3 when the output of comparator **236** will change state. In essence, during the zero calibration process, transistor **210** is never turned on thereby determining the timing conditions of what would effectively be a zero flight time. Therefore, if there is no charge current applied to capacitor **244**, T_3-T_0 zero is the time that would be in the microcomputer **270** and the timer in whatever units they operate, which is usually dependent on the CPU section **28** crystal frequency. In the embodiment shown, the microcomputer **270** utilizes an 8 MHz crystal and the internal timer has a 1.5 microsecond resolution resulting in a count of about 150.

During the fixed pulse width calibration process (shown particularly in FIG. **7D**) at time T_4, once again the microcomputer **270** stops the TIMER and a short time later at T_5 it releases the clamp. At T_6, a known pulse width is applied to the base terminal of transistor **210** which is precisely derived from the main oscillator **30** as applied to the CLK input of the shift register **160**. The signal applied to the CLK input of the shift register **160** directly tracks the main oscillator **30** and the serial data input to the shift register **160** is a logic line **154** from the CPU section **28** designated NORM/CAL. When the NORM/CAL signal is high, the precision timing section **34** is in its normal mode of operation and, when it drops to a logic low state, the fixed pulse width calibration function is initiated. Thereafter, typically about fifty microseconds later, at time T_6 the NORM/CAL signal on line **154** will be dropped low. It should be noted that during both the zero and the fixed pulse width calibration modes, the logic reset signal /RESET on line **156** is held low, its active state. In the logic low state the two flip-flops **158**, **162** determine whether the input signal comes from shift register **160** which generates the fixed pulse width or whether it comes from the REF and RX(OUT+) signals an relates to an actual laser flight time. The /RESET signal is generally held low at all times during the fixed pulse width calibration process so that any noise on the RX(OUT+) receive line **100** will not accidently clock flip-flop **162** and therefore trigger the precision timing section **34** resulting in an indeterminate time period measurement invalidating the calibration. The reset state for the Q outputs of flip-flops **158**, **162** is low but is high for the $\overline{\text{Q}}$ outputs. Therefore, the $\overline{\text{Q}}$ outputs can not be directly driven with the reset circuit and must be driven off the Q outputs in both cases which introduces a small fixed offset delay which must be

accounted for later. As soon as the NORM/CAL signal on line **154** is dropped low, which occurs approximately 50 microseconds after the clamp has been released, the low signal propagates through the shift register **160** precisely with the main oscillator **30** clock. The Q0 output of the shift register **160** is the first to be triggered but is not used because it is used to synchronize with the incoming signal. The Q1 is then the first output of the shift register **160** to be utilized and on every positive edge of the clock the zero signal that is applied into the serial input will propagate one state of the shift register **160** from Q zero to Q7. Therefore, the Q1 output will go low first, and as soon as that output goes low, the set line input $\overline{S}$ forces the Q output of flip-flop **158** to go high since the Q output of flip-flop **162** is in the low state. As a result, logic level ones appear at the two inputs of the transmit gate **204**, which turns on the current switch transistor **210**. Exactly six clocks later, the same thing happens with flip-flop **162** which has its $\overline{S}$ input coupled to the Q7 output of the shift register **160**. As the Q output of flip-flop **162** goes high, the output of the invertor **202** goes low, and the transmit gate **204** will be turned off. At this point the count pulse will stop meaning that the fixed width pulse feeding the current switching circuit at the output of the transmit gate **204** is precisely six clock cycles. The time difference between the Q1 and Q7 outputs of the shift register **160** is exactly 750 nanoseconds when utilizing an 8 MHz oscillator **30** applied to its CLK input. The invertor **202** adds an additional delay of about 10 nanoseconds for a total of delay of about 760 nanoseconds which varies only slightly with temperature, perhaps one or two nanoseconds, yet still provides sufficient precision for measurements of less than one yard resolution.

Transistor **210** is then turned on for a period of time between T_6 and T_7 to enable the capacitor **244** to charge very rapidly and then discharge at the same rate as has been previously shown with respect to FIG. **7**A. As V1 reaches the level of V2 the TIMER signal goes low at Time T_8. The fifty microsecond delay between the unclamping at T_5 and T_6 is to allow the clamp transistor **214** to turn off fully since it is a relatively inexpensive bipolar device. If a MOSFET were used instead, its turn off would be virtually instantaneous and the additional delay it introduced would not be a problem because the microcomputer **270** couldn't issue the next instruction quickly enough. Utilizing a bipolar device, approximately 20 microseconds are required for the discharge to become linear and the slope of the discharge curve between T_7 and T_8 is then identical to the slope from T_1 to T_3 in the zero calibration mode except for the step due to the charging of capacitor **244**. As a consequence, the value of $ZERO_{TIME}$ equals T_3 minus T_0 and the value of CAL_{TIME} value equals the time due to the CAL_{TIME} value not due to the $ZERO_{TIME}$ value, which is, T_8 minus T_4 minus the $ZERO_{TIME}$ value or, T_8 minus T_3.

In essence then, very small flight times are effectively disregarded and the value of CAL_{TIME} is known. Therefore, with the zero calibration function and the addition of a known calibrated pulse width, the time delay at zero is known together with the time delay for the known pulse width providing the origin and scale for determining distance with a constant linear discharge of capacitor **244**.

With particular reference additionally to FIG. **7***c*, the operation of the precision timing section **34** is shown in the laser measurement mode of operation. The laser measurement operation is essentially the same as the fixed pulse width calibration mode except that the NORMAL/CAL signal on line **154** to the shift register **160** is held high and the /RESET signal on line **156** is taken high at time T_9 to enable the flip-flops **158**, **162** to trigger. At time T_{10} the timer is started and at T_{11}, (at precisely the same relationship T_{11} minus T_{10} equals T_5 minus T_4 equals T_1 minus T_0) the clamp is released. There is normally a fifty microsecond wait and then the laser pulse is fired when the microcomputer **270** asserts the /FIRE signal on line **80** to initiate the firing sequence. Upon firing the laser emitting diode **20**, the laser transmit section sends the REF signal on line **94** to the CLK input of flip-flop **158** of the precision timing section **34**. This opens the transmit gate **204** which turns on the current source transistor **210**, which, in turn, charges capacitor **244** at a known rate.

When the reflected laser pulse is detected by the laser receiving diode **24** of the laser receive section **22** (shown in FIG. **3**), the RX(OUT+) signal on line **100** is directed to the CLK input of flip-flop **162**. The Q output signal of flip-flop **162** is inverted by invertor **202** which turns off the transmission gate **204** so that the current source transistor **210** is on for the flight time duration of the laser pulse to charge capacitor **244** to a level determined by the timer during that flight time. The charge applied to the capacitor **244** may be anything from just a few millivolts (essentially zero distance and flight time) to up to two volts (maximum range and flight distance) depending on the distance to the target. Time T_{12} represents the firing of the laser as indicated by the REF signal and T_{13} represents the receipt of the reflected laser signal as indicated by the RX(OUT+) signal. Transistor **210** is turned on at T_{12} and turned off at T_{13}. As a consequence, V1 will equal V2 at anytime between T_{14A} (minimum distance when T_{12} and T_{13} are essentially coincident) and T_{14B} (maximum range of the laser range finder **10**). Times T_{14A} through T_{14B} represent the range of times (depending on the distance to the target) when the value of V1 is discharged below the level of V2 and the comparator **236** output changes state stopping the timer.

The actual laser flight time $LASER_{TIME}$ (or $FLIGHT_{TIME}$) then equals T_{14A} (or T_{14B}) minus T_{10} minus $ZERO_{TIME}$ or, T_{14} minus T_{13}. The time T_8 has to be greater than T_3, and T_{14} is greater than or equal to T_3. There is no theoretical limit on the lower range of the laser range finder **10** and flight time (and distance) can be measured down to zero due to its linearity. The only factors in the near zero range are the time it takes transistor **210** to turn on, the propagation time of the laser beam and the various circuit gates, but since the time for each of these factors is the same during calibration as during flight time, they essentially cancel out. The precision timing section **34** can be effectively utilized down to on the order of ten nanoseconds and still remain perfectly linear. RANGE to a target is then a constant, "k" times the quantity $FLIGHT_{TIME}$–$ZERO_{TIME}$ over CAL_{TIME}–$ZERO_{TIME}$.

For each of the values: $ZERO_{TIME}$, CAL_{TIME} and $FLIGHT_{TIME}$ values are accumulated and are expressed in time units that derive from the very accurate crystal oscillator **30**. Typically, ten pulses may be utilized to establish the $ZERO_{TIME}$ average, ten pulses to establish the CAL_{TIME} average and ten pulses to establish the minimum precision (or rough) $FLIGHT_{TIME}$ range to the target. Another group of ten through thirty laser pulse $FLIGHT_{TIME}$s may be also averaged in order to obtain a higher precision distance to a target as indicated by a "precision flag" which may be displayed on the LCD display **32** within the laser range finder **10** eyepiece. Nevertheless, the actual values derived in these time expansions will, of course, vary with time, temperature and aging and affects the gain of the transistors, the leakages, as well as the value of the resistances and capacitances. Initially the exact values of these effects are completely unknown but, through the use of the zero and

calibration functions above-described, the zero problem has been eliminated, and a crystal reference calibration has been provided for the entire flight time without having to resort to a complicated counter circuitry.

Another aspect of the precision timing section **34** is the automatic set noise control and invertor **168** provides, in conjunction with other circuit elements, a hardware hold off function. Upon firing of the laser and receipt of the reference signal REF on line **94** at the CLK input of flip-flop **158**, a certain time must elapse, as determined by the time constant of resistor **164** and capacitor **166**, before the D input goes high. Until that time, all noise pulses and/or early laser pulses on the clock line are ignored. The purpose for this function is that, when the laser fires, it generates unintended ground bounce and noise that may prematurely rigger the receive flip-flop **162** rather than the real laser return signal (RX(OUT+). For that reason, a hold off period is provided corresponding to the minimum range of the laser range finder **10** and, as an example, considering a minimum range of about twenty yards, the holdoff time is approximately 60 nanoseconds. With a lower sensitivity laser range finder **10** utilized at shorter ranges the function can be eliminated and it is clearly most useful with a high sensitivity receiver where the noise from the firing circuit determines an effective minimum range.

Transistor **174** provides an additional function and allows the microcomputer **270** to extend the hold off range by asserting the HOLD OFF signal on line **258**. In this manner, the minimum range of the laser range finder **10** may be extended out to, for example, sixty or eighty yards, whatever is the desirable setting. This microcomputer **270** hold off function may be implemented by the mode switch **126** and would allow shooting through branches, twigs, precipitation or other partial obstructions. Be extending the hold off range out beyond such partial obstructions, there is insufficient back scatter from the obstructions to trigger the precision timing section **34** and the measurement will be made to the desired target instead of the intervening obstructions. This is accomplished by now allowing flip-flop **162** to trigger until a set timer period has elapsed. Transistor **174** is the switching device utilized to allow setting of an extension to the hold off range and gate **180** is used to determine the receive pulse width in conjunction with the discharge rate of capacitor **194**. This allows the microcomputer **270**, which has a built in analog-to-digital ("A/D") convertor, to determine the residual voltage on capacitor **194** and therefore derive a measure of the pulse width, (which is a measure of the return signal power) and thus use an internal lookup table to correct for that power variation and get a higher range accuracy. When the logic reset signal /RESET on line **156** is low, transistor **190** clamps capacitor **194** to the +5 volt rail. During the laser measurement routine, the transistor **190** is turned off. When a pulse subsequently arrives, that bit turns on transistor **200** and the voltage in capacitor **194** will be discharged via resistor **198** for the duration of that pulse. The charge on capacitor **194** is then digitized by the processor to determine the effect of incoming power.

With reference additionally now to FIG. **8**, the automatic noise threshold section **36** of the laser range finder **10** is shown. The automatic noise threshold section **36** receives the RX(OUT+) signal from the laser receive section **22** (shown in FIG. **1**) on line **100** for input thereto through resistor **314**. Resistor **314** is connected to the anode of diode **316** which has its cathode connected to the "+" input of operational amplifier ("OpAmp") **318** forming a V_3 node **320**. V_3 node **320** is coupled to circuit ground through the parallel combination of resistor **322** and capacitor **324**. The output of OpAmp **318** is coupled back to the "−" input thereof as well as to line **102** through resistor **326** for supplying the $V_{threshold}$ signal to the laser receive section **22** (shown in FIG. **1**). Line **102** is connected through resistor **330** to the center tap of potentiometer **332** which has one terminal thereof connected to a source of +5 volts through resistor **334** and another terminal thereof coupled to circuit ground through resistor **336**.

Lines **308** and **310** from the microcomputer **270** (shown in FIG. **6**) are connected through resistors **338** and **330** respectively to line **102**. Additionally, line **312** from microcomputer **270** is connected to line **102** through resistor **342** as shown.

In operation, the automatic noise threshold section **36** in conjunction with the CPU section **28** (shown in FIG. **6**) provides a simply implemented yet highly effective threshold adjustment to the laser receive section **22** (shown in FIG. **3**) As shown in FIG. **3**, the laser receiving diode **24** utilizes a high-voltage source (of about 50 volts) supplied via a noise filtering network, comprising low pass filter network **106**, to bias it. The diode **24** responds with an output current proportional to the incoming laser light which is generally a short duration laser pulse producing a short current pulse which is amplified by transistors **118**, **120**, **122**, **124**, comprising the active circuit elements of a transimpedance amplifier **116**. The transimpedance amplifier **116** produces an output voltage pulse proportional to the incoming laser pulse impinging on the laser receiving diode **24**. The output of the transimpedance amplifier **116** is capacitively coupled to the "+" input of comparator **134**, which is a high speed comparator. When the laser pulse input to the "+" input crosses a threshold determined by the voltage on the "−" threshold pin, a positive output pulse is produced.

To maximize performance, the threshold of the comparator **134** has to be set for maximum sensitivity in order detect the weakest possible laser pulse to get the maximum performance out of the laser range finder **10**. Conventional approaches include using digital controls or a potentiometer to adjust the threshold. However, these approaches have the down side that over time and temperature changes the gain of the receiver will change with the background noise generated by the background light rendering a fixed threshold as less than an ideal solution.

The automatic noise threshold section **36** of FIG. **8** discloses a circuit that automatically sets a threshold such that a constant noise pulse firing rate is output from the detector comprising resistor **314**, diode **316**, capacitor **324** and resistor **322**. In operation, when the threshold pin of the comparator **134** (FIG. **3**) is at a considerably higher voltage than the input pin, no noise pulses will appear at the output due to the inherent amplifier and optically generated noise. As the voltages on the threshold and input pins are brought closer together, noise pulses will appear at the output and, when the voltage levels are nearly coincident, a great deal of noise can be seen. In essence then, the automatic noise threshold section **36** sets the noise pulse rate at that point at which, given the right firmware algorithm, one can still acquire the target and not be blinded by the noise. The higher the noise that can be tolerated, and the closer the voltage levels at the threshold and input pins of the comparator **134**, the weaker the laser pulse that can be detected. The automatic noise threshold section **36** automatically adjusts that threshold level to maintain constant noise pulse firing rate.

As shown in FIG. **8**, this is accomplished by monitoring the digital logic receive signal RX(OUT+) on line **100** that goes to the receive flip-flop **162** (shown in FIG. **4**). The

detector monitors line **100** for the presence of noise pulses via a detector comprising the aforementioned resistor **314**, diode **316**, capacitor **324** and resistor **322**. The value of resistor **322** is typically considerably greater than that of **314**, on the order of a 150:1 ratio. The peak amplitude of the noise pulses is typically at or near the logic threshold, except for very narrow pulses where the comparator will not reach full amplitude, however, the width of these pulses is going to vary randomly because it depends on the noise signal that is being detected. Moreover, the spacing of the noise pulses will also vary at a random rate, but, for any given threshold setting, there will be a fixed average rate. The average rate is dependent on the threshold. Therefore, during the time the pulse is high, capacitor **324** charges via resistor **314** and diode **316** at a rate determined by the high on the logic pulse, resistor **314** and whatever voltage is still existing or capacitor **324**.

Initially, capacitor **324** is charged as follows. once the noise pulse terminates, the logic line goes back to zero. There is a residual voltage on capacitor **324**, diode **316** will be reverse biased, and the discharge path is now via resistor **322**. (As previously described, the value for resistor **322** is chose to provide a relatively longer time constant, a factor of 150.) When another pulse comes in, capacitor **324** will charge a bit more. What will then happen is, quite rapidly, (i.e. within a few milliseconds) the voltage across capacitor **324** stabilizes at a rate that is proportional to the average firing rate. The reason for having a large ratio between resistor **314** and resistor **322** is because the noise pulses typically may average 50 nanoseconds wide, and the averaged time between them to maximize the sensitivity of the laser range finder **10** should be of the order of the two microseconds or so. As an example, of a 50% voltage were desired, and the high state was occurring for 50 nanoseconds while the low state average was occurring for one microsecond, a 20:1 ratio would be produced. Nevertheless, the optimum ratio has been determined empirically to be about 150:1 as previously described and is related to average pulse widths (typically on the order of 30 nanoseconds in length) and pulse repetition rates (on the order of 4 microseconds) with a typical voltage level of 1.5 volts.

Op amp **318** is configured as a unity gain buffer, although it need not be unity gain, with a voltage **V3** at its "+" input pin on node **320**. The input is high impedance and the output is low impedance in order to drive external circuitry. The voltage that is derived at the output of the op amp **318** is then fed into a resistor network comprising resistor **338**, resistor **340**, resistor **342** and resistor **330**. A summing node of the resistor network on line **102** goes to the threshold control to provide the signal $V_{threshold}$ to the laser receive section **22** (shown in FIG. **3**). Resistor **330** is connected to the center tap of a potentiometer **332** so that the DC voltage on the other end of resistor **330** can be controlled.

In combination, the circuit comprises a feedback network such that, if there are no noise pulses, then **V3** is zero and $V_{threshold}$ and drops to a low value. Initially, $V_{threshold}$ will be higher, and the "−" input of comparator **134** (shown in FIG. **3**) will be higher than the "+" input, forcing a logic low on the output as the starting state. As the level of **V3** on node **320** falls, the voltage level on the "−" pin of comparator **134** starts approaching the level of the signal from the transimpedance amplifier **116** on the positive "+". When it approaches the noise zone, noise pulses start appearing. As soon as noise pulses start appearing, a charge appears on node **320**, so **V3** stops to charge up, and when the two match, that's the feedback point and it stops. Basically, the voltage on the threshold is set at such a point that the noise firing rate maintains **V3** at that voltage which is necessary to maintain $V_{threshold}$. Because very small changes in $V_{threshold}$ make a very large change in the noise firing rate, typically, a ten millivolt change in $V_{threshold}$ will change the voltage **V3** at node **320** by about a volt. What is produced then, is a fairly high gain feedback loop, such that $V_{threshold}$ will track very closely the noise firing rate and **V3** will stabilize very accurately and rapidly. This further provides the capability to adjust the noise firing rate by controlling the bias and forcing **V3** to compensate. The voltage **V3** at node **320** then represents the noise firing rate.

NSET1 line **308** and NSET2 line **310**, are two control lines from the microcomputer **28** such that when held low or high, adjusts the noise rate to obtain the maximum range to different reflectivity targets. If both lines **308** and **310** are taken high, **V3** will drop to compensate to maintain a constant threshold noise. Similarly, potentiometer **332** provides an adjustment such that the threshold point may be set together with the level of **V3**. Typically, the **V3** point might be set equal to: 0.5, 1.0, 1.5 and 2.0 volts as desirable choices for the average noise firing rates. As such, since resistor **338** is approximately twice the value of resistor **340**, four voltage combinations are obtained roughly equally spaced in voltage by half a volt. Potentiometer **332** is used to set the first voltage level to 0.5 or the last one to 2.0 while the intervals are determined by the logic control lines **308** and **310** set NSET1 and NSET2. Obviously, this approach could be extended, four combinations provides adequate resolution in the particular implementation of the laser range finder **10** described and shown. When both lines **308** and **310** are high, there is a current injected into the node comprising the $V_{threshold}$ line **102**, and to compensate for that, **V3** must drop, so less current flows through resistor **326** and vice versa. **V3** will follow these values, depending on the permutations of logic high and low signals on the lines **308** and **310**. Resistor **330** is used just to set where this whole block resides while potentiometer **332** is used to establish the initial set point. Since the noise characteristics from unit to unit will vary somewhat, potentiometer **332** enables the setting of the initial device characteristics.

Resistor **342** is of a considerably lower value than resistors **338** and **340** and its value is chosen such that, when the REFLECTOR MODE signal on line **312** is asserted by being taken high, **V3** will drop to zero and will stay there because it cannot go below zero. At this point, the feedback loop is saturated and is no longer effective, so $V_{threshold}$ is no longer stabilized. In operation, line **312** will be pulled high by a considerable voltage, on the order of 0.4 volts, such that it completely desensitizes the laser receive section **22** so the laser range finder **10** will then only respond to a retro reflector. In this mode of operation the receiver is detuned and its noncooperative range drops from 500 yards down to about 30 or 40 yards, such that the laser range finder **10** only latches onto a retro reflector or survey prism comprising a high grade reflector that returns the laser energy back to the source. Possible applications also include determining the distance to a particular golf hole where a laser reflector is attached to the pin and the signal might otherwise be actually returned from trees behind or in front of the green in a more sensitive mode of operation.

The essence of the automatic noise threshold section **36** is, as previously described, a feedback loop comprising the detected average noise firing rate forming a feedback loop that controls the threshold. Use of this circuit has resulted in an addition of almost 50% to the range of the laser range finder **10** compared to attempting to manually set the threshold. By setting the noise firing rate, noise pulses are being

produced deliberately, all the time and the only way you to take advantage of that fact is by implementing a firmware algorithm in the microcomputer **270** that allows you to discriminate between noise pulses and laser return pulses. What the algorithm does is, during the laser firing process, on the first pulse that fires, it gets a laser pulse, and it places it in a stack of pulses. For example, the stack may have locations designated 0 through 9, to enable 10 pulses to be maintained in the stack. The values of the $FLIGHT_{TIME}$ are saved, corrected for power return, (the microcomputer **270** determines the power level of the return signal and corrects the flight time for power return) and placed in one of the locations in the stack. Upon receipt of the next pulse, the microcomputer **270** will then compare the next pulse with the remaining locations in the stack. Initially, most of the locations will be empty, and there will be no match. If no match is found, the microcomputer **270** puts the pulse in the stack and carries on, merely placing pulses in the stack, and then when it gets to the top, it goes back and overwrites the base, so you have a history of N number of pulses in the stack. Any time a new pulse comes in, it compares the entire stack for a match, where N=10, it searches the preceding ten pulses for a match.

The reason for doing that is, since a high noise firing rate has been deliberately set to get maximum sensitivity, many noise pulses are going to have shown up, but the noise pulses will be of random occurrence and the chance of a precision match is very low. Because the tolerance can be set as any other firmware parameter, a default value will be typically loaded that has been determined empirically. As an example, a tolerance of a few nanoseconds may be set for a match to be assumed to be a real target and not a noise pulse. Utilizing the algorithm, the process continues, trying to lock on the target until a match is achieved. The match need only be two pulses within the preset tolerance (providing very acceptable results) or, if higher sensitivity were desired, a match of three through N may be specified, depending on the reliability needed to guarantee a real target and not a noise pulse. In an exemplary operation, the first pulse (pulse **0**) could be the real target, followed by eight noise pulses, and as long as the ninth pulse is again the real target, the distance to the target can be accurately determined. The stack can be increased in size up to whatever memory limit is available in the system, depending on how far into the noise level the laser range finger **10** must work.

Having found a match, the average of the match values may then be used to compare all subsequent pulses, rather than needing to place them in a stack and only pulses that match up with that initial match average will contribute to the measurement. If a certain number of pulses elapse before another matching pulse is received, it may be assumed that an accidental lock-on to noise has been achieved and the process restarts. By adjusting the various parameters, a trade off can be made between the time it takes to get a measurement to how far into the noise the laser range finger **10** must work. Because the noise rate can set to whatever is desired by means of the automatic noise threshold section **36**, it is possible to optimize the algorithm to provide the optimum acquisition characteristics against time and against range.

The higher the value of V3, the more noise is coming out of the receiver, and the more sensitive the laser receive section **22** is running. The probability of a noise pulse showing up is proportional to the flight time, so given a very "black" target, the maximum range will be less, but the maximum flight time is also less, so a higher noise rate can be tolerated. Therefore, running at a higher gain will provide the best range to a black target. On the other hand, if the target very reflective, a high gain is not required, so the noise rate can be lowered, which then provides the same probability of a noise pulse appearing over a longer flight range, and therefore a quick acquisition on a bright white target can be achieved. Thus, by depressing the mode switch **126**, different modes of operation of the laser range finder **10** can be selected. As an example, one mode might be utilized to find the range to reflective road signs out to a distance of 1000 yards or more. Alternatively, aiming the laser range finder **10** at something like wet black tree bark, might reduce the maximum range to only 350–400 yards and so a different operational mode might be selected which would otherwise require a relatively long time to hit the road sign, if ever, because there would always be a noise pulse in the way. The mode switch allows the setting of these variables to maximize the range of the laser range finder **10**, depending on the target quality and a visual indication of the target quality selected may be provided to the operator on the insight, LCD display **32** wherein the first mode would correspond to the brightest target or most reflective target, and the Nth mode would correspond to the least reflective target.

While there have been described above the principles of the invention in conjunction with specific apparatus, it is to be clearly understood that the foregoing description is made only by way of example and not as a limitation on the scope of the invention.

What is claimed is:

1. A laser range finder comprising:

a laser transmitting section for producing a series of transmitted laser pulses directable towards a target and producing a plurality of returned laser pulses at least partially reflected therefrom in response thereto;

a laser receiving section for receiving said plurality of returned laser pulses and noise pulses, said laser receiving section comprising a laser signal receiving device coupled to an input of a transimpedance amplifier, said transimpedance amplifier providing an amplified output signal of said laser signal receiving device for input to a comparator circuit for providing an automatic noise threshold adjustment to said laser receiving section to facilitate discrimination between said returned laser pulses and said noise pulses;

a central processing section coupled to said laser transmitting and laser receiving sections for determining a distance to said target based on a time of flight of said transmitted and returned laser pulses; and

a user viewable display coupled to said central processing section for displaying said distance to said target.

2. The laser range finder of claim **1** wherein said laser signal receiving device comprises a laser receiving diode.

3. The laser range finder of claim **1** wherein said comparator circuit comprises a precision comparator.

4. The laser range finder of claim **3** wherein said precision comparator comprises a MAX 913 precision comparator.

5. The laser range finder of claim **1** wherein said transimpedance amplifier is capacitively coupled to an input of said comparator circuit.

6. The laser range finder of claim **5** wherein said input of said comparator circuit is further coupled to a voltage

divider network comprising first and second resistors coupling a supply voltage source to a reference voltage level.

7. The laser range finder of claim **1** wherein said comparator circuit sets a substantially constant noise threshold firing rate.

8. The laser range finder of claim **7** wherein said substantially constant noise threshold firing rate is set by means of a resistor/capacitor network.

9. The laser range finder of claim **8** wherein said resistor/capacitor network couples an output of said comparator circuit to a threshold voltage input thereof.

10. The laser range finder of claim **9** wherein said resistor/capacitor network comprises at least one resistive element coupled to said output of said comparator circuit and coupled in series with at least one capacitive element coupled to a reference voltage level, said resistive and capacitive elements having a circuit node therebetween.

11. The laser range finder of claim **10** wherein said circuit node is coupled to said threshold voltage input of said comparator circuit.

12. The laser range finder of claim **11** wherein said laser signal receiving device is further coupled to a power supply source through a low pass filter network.

13. The laser range finder of claim **12** wherein said low pass filter network comprises at least one resistive element coupling said power supply source to a first terminal of said laser signal receiving device, a second terminal of said laser signal receiving device being coupled to said input of said transimpedance amplifier, said low pass filter network also comprising at least one capacitive element coupling said first terminal of said laser signal receiving device to a reference voltage level.

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